# Carbon Dioxide for Enhanced Gas Recovery and as Cushion Gas

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## RESEARCH OBJECTIVES

Natural gas reservoirs are obvious targets for carbon sequestration by direct carbon dioxide ($CO_2$) injection, because of their proven record of gas production and integrity against gas escape. Carbon sequestration in depleted natural gas reservoirs can be coupled with enhanced gas production by injecting $CO_2$ into the reservoir as it is being produced, a process called Carbon Sequestration with Enhanced Gas Recovery (CSEGR). In this process, supercritical $CO_2$ is injected deep in the reservoir while methane ($CH_4$) is produced at wells some distance away. The active injection of $CO_2$ causes repressurization and $CH_4$ displacement to allow the acceleration and enhancement of gas recovery relative to water-drive or depletion-drive reservoir operations. Carbon dioxide undergoes a large change in density as $CO_2$ gas passes through the critical pressure at temperatures near the critical temperature. This feature makes $CO_2$ a potentially effective cushion gas for gas storage reservoirs. Thus at the end of the CSEGR process when the reservoir is filled with $CO_2$, additional benefit of the reservoir may be obtained through its operation as a natural gas storage reservoir. The objective of this research is to demonstrate by numerical simulation the potential sequestration-related uses of $CO_2$ in natural gas reservoirs.

## APPROACH

We have developed a new module called TOUGH2/ EOS7C for simulating natural gas reservoirs under $CO_2$ injection. TOUGH2/EOS7C considers five mass components (water, brine, $CO_2$, gas tracer, $CH_4$) and heat. For the gas mixture properties, new real gas mixture subroutines were developed to calculate density and enthalpy departure in the system $H_2O$-$CO_2$-$CH_4$ using the Peng-Robinson equation of state and an accurate gas mixture viscosity model. We use this new module to carry out numerical simulations of $CO_2$ injection and $CH_4$ production in model natural gas reservoirs.

## ACCOMPLISHMENTS

We have carried out numerous simulations of $CO_2$ injection, $CH_4$ production, and natural gas storage with $CO_2$ as a cushion gas. We present here simulation results for a comparison of native gas ($CH_4$) and $CO_2$ cushion gases in a model gas storage reservoir. In Figure 1, we show a schematic of a natural gas storage reservoir showing cushion gas which is not produced, but which compresses upon injection of the working gas ($CH_4$), and which expands to help produce the working gas ($CH_4$) upon $CH_4$ withdrawal. As shown in the pressure vs. time part of the figure, the pressure rise in the reservoir for a given $CH_4$ injection rate is lower with the $CO_2$ cushion gas than for a native gas cushion. If the $CH_4$ injection rate is cut to 70% of the original rate, the pressure rise with a native gas cushion is comparable to the full $CH_4$ injection rate with $CO_2$ as cushion gas. In short, more working gas can be injected using a $CO_2$ cushion than for a native gas cushion. The reason for this is the extreme compressibility of $CO_2$ around the critical pressure in the 40°C reservoir.

## SIGNIFICANCE OF FINDINGS

These simulation results show that $CO_2$ could be a very effective cushion gas for natural gas storage. Such a use of the reservoir would follow active $CO_2$ injection that could be used for enhanced gas recovery in a depleting gas reservoir. Our simulations over the last few years show that $CO_2$ may be a potentially useful gas for both enhancing gas recovery in depleted gas reservoirs, and for use as a cushion gas once the reservoir is filled with $CO_2$.

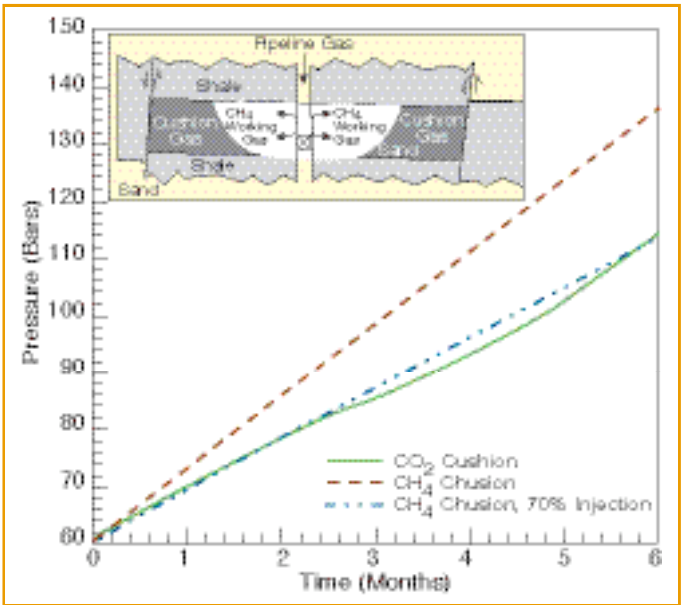


Figure 1. Schematic of natural gas storage and pressure vs. time for one cycle of $CH_4$ injection with various cushion gases showing the lower pressure rise for $CO_2$ cushion gas relative to a native $CH_4$ gas cushion.

## RELATED PUBLICATIONS

Oldenburg, C.M., Carbon dioxide as cushion gas for natural gas storage, Energy and Fuels, 17(1), 240–246, 2003.

Oldenburg, C.M., S.H. Stevens, and S.M. Benson, Economic feasibility of carbon sequestration with enhanced gas recovery (CSEGR), Energy, 2003 (in press).

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